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The Question of Presolar Components within Interplanetary Dust Particles (IDPs) Collected in the Stratosphere

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Abstract. Interplanetary dust particles (IDPs) are from asteroids and comets, and they are the smallest and most fine-grained meteoritic objects available for laboratory investigation. Cometary IDPs are of special significance because they are presently the only samples of comets, and comets are expected to be enriched in preserved solar nebula and presolar components. These components may include not only cosmically rare refractory circumstellar grains (e.g. SiC) that are recovered from meteorites but also cosmically abundant interstellar silicates and carbonaceous grains that were the fundamental building blocks of the Solar System. D/H ratios measured in IDPs are consistent with the survival of interstellar carbonaceous material, and some IDPs contain glassy grains with properties similar to those of interstellar "amorphous silicates". Submicrometer forsterite and enstatite crystals in IDPs resemble circumstellar silicates detected by the Infrared Space Observatory (ISO). ISO also detected a broad $\sim$ 23 μm feature around several stars, and a similar feature observed in IDP spectra is due to submicrometer FeNi sulfide grains, suggesting that sulfide grains may be a significant constituent of astronomical dust.

Some chondritic interplanetary dust particles (IDPs) collected in the stratosphere are from comets (Brownlee et al. 1995; Flynn 1996; Liou & Zook 1996). Despite their small sizes (Fig. 1), advances in microanalytical technology have made it possible to measure their optical properties, compositions, and mineralogy using synchrotron light sources, ion microprobes, and electron microscopes. Coupled with new observational data about dust grains in cometary, circumstellar, and interstellar environments (Sitko et al. 1999; Wooden et al. 1999; Hanner et al. 1997), it is now possible to directly compare the properties of IDPs with dust in space (e.g. Bradley et al. 1998, 1999; von Helden et al. 2000).

Astronomical spectral features resulting from some of the more abundant materials thought to exist in space include the $\sim$220 nm UV feature, the $\sim$3.4 μm organic C-H stretch feature, and the $\sim$10 and $\sim$20 μm IR features. The $\sim$220 nm and $\sim$3.4 μm features are due to carbonaceous grains and the $\sim$10 and $\sim$20 μm IR features are due to silicates (Sandford 1996). Isotope measurements suggest that some IDPs contain presolar carbonaceous components. D/H and $^{15}N/^{14}N$ ratios in chondritic meteorites have been attributed to surviving interstellar molecular carbon that has been diluted and modified by alteration on the meteorite parent bodies. Similar H and N isotopic anomalies are observed in chondritic IDPs (Fig. 2) but the anomalies are sometimes far larger than

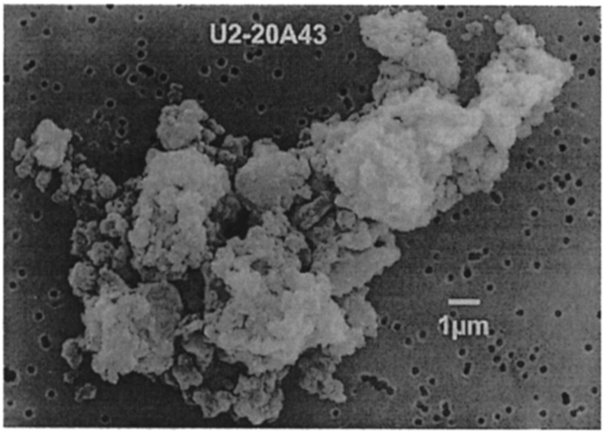

Figure 1. Secondary electron image of anhydrous chondritic porous ("CP") interplanetary dust particle U2-20A43. The calculated atmospheric entry speeds of some CP particles, derived from solar wind helium release measurements, suggest that they are from comets (see Brownlee et al. 1995).

those in meteorites (similar to the values of interstellar molecules), suggesting that interstellar carbonaceous grains have survived intact in IDPs (Messenger 2000). Therefore, it is logical to assume that other common interstellar grains may also be present in IDPs.

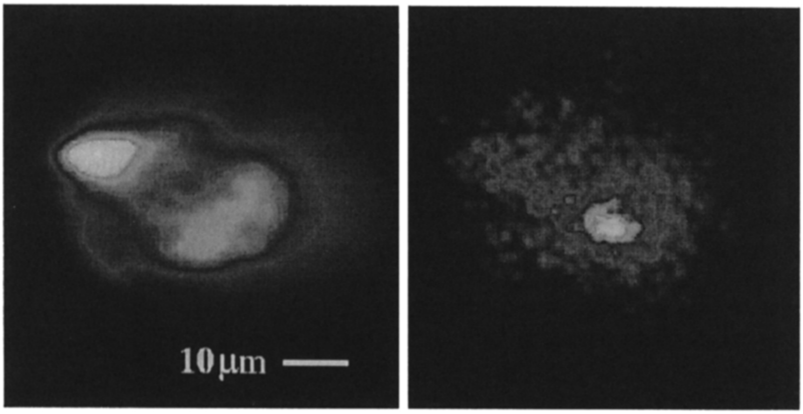

Figure 2. Hydrogen isotopic images of a deuterium-rich IDP showing spatial distributions of H (left) and (D) with a 1-2 μm "hot spot" (right). The magnitude of the D enrichments in some IDPs is similar to those of interstellar molecules suggesting preservation of pristine molecular cloud material. (Images from Messenger 2000).

Some components of IDPs resemble interstellar silicate grains. Glassy grains known as GEMS (glass with embedded metal and sulfides) possess exotic min-

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eralogical properties that match those inferred for interstellar "amorphous silicates" (Bradley 1994). The infrared ~10 μm silicate feature of GEMS has been measured using a high brightness synchrotron light source and it is similar to those of interstellar silicates and dust in young stellar objects (Bradley et al. 1999). The similarity is intriguing because attempts to fit the 10 μm astronomical silicate feature in a wide variety of environments (circumstellar, dense and diffuse ISM, young stellar objects, and comets) using the spectra of a variety of natural and synthetic silicates have been unsatisfactory. Whether GEMS truly are the grains responsible for the ~10 μm (and ~20 μm) "amorphous silicates" features observed in astronomical spectra may require measurement of the isotopic compositions of individual GEMS using a new generation of ion microprobe known as nanoSIMS (Stadermann et al. 1999).

Crystalline silicate grains in IDPs resemble circumstellar silicates detected by the Infrared Space Observatory (ISO). ISO detected submicrometer crystals of forsterite (Mg_2SiO_4) and enstatite ($MgSiO_3$) around young and old stars (Waters et al. 1998). Such grains are extremely rare in meteorites, which may explain why despite a prolonged search not a single (isotopically anomalous) presolar silicate grain has yet been unambiguously identified in any meteorite. In contrast, submicrometer forsterite and enstatite grains are major constituents of the anhydrous chondritic subset of IDPs of probable cometary origin (Bradley et al. 1999). Future isotope measurements of these tiny crystals in IDPs using nanoSIMS may clarify whether they formed within the Solar System or around other stars (Wooden et al. 2000).

A ~3.4 μm hydrocarbon feature similar to the astronomical 3.4 μm feature has been detected in carbon-rich IDPs (Brownlee et al. 2000). The astronomical feature is seen in stars lying behind relatively small columns of diffuse material and it appears not to have a threshold below which it disappears. This implies that the 3.4-μm band carrier survives relatively harsh diffuse ISM conditions and therefore may survive Solar System formation and be well preserved in some IDPs. The 3.4 μm feature observed in IDPs may be related to the carrier(s) of the D/H and N anomalies (Messenger 2000).

Preliminary UV absorption measurements of IDPs and standards over the wavelength range 180-260 nm have been made using a synchrotron light source, with the goal of searching for a ~220 nm feature in IDPs (Gezo et al. 2000). Measuring the UV spectral properties of IDPs is difficult (relative to IR measurements) because specialized optics are required and UV transmission through typical meteoritic material is limited to very thin samples (ideally $< 1\mu$m thick). Whether carbon-rich IDPs exhibit a ~220 nm feature has not yet been established.

A broad ~23 μm feature observed in ISO spectra of several stars has been attributed to wuestite (FeO) (Henning et al. 1995). Using the synchrotron light source it has been shown that the ~23 μm feature is inconsistent with wuestite (and other Fe oxides) and instead consistent with Fe-rich sulfides similar to those found in IDPs (Keller et al. 2000). This finding suggests that sulfide grains may be a significant component of astrophysical dust. All of the above observations raise the exciting prospect that some IDPs may be composed either in part or entirely of pristine assemblages of presolar interstellar and circumstellar material.

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